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A NEW METHOD TO PROBE THE LOW x PARTON DYNAMICS AT HERA

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Abstract

Hadron transverse momentum spectra are proposed as a means to probe the underlying partonic dynamics in deep inelastic scattering. The BFKL evolution equation, postulated for small Bjorken-x, leads to an enhanced parton emission over the conventional DGLAP ansatz, and can thus be tested.

1 Introduction

The successful description of the nucleon structure function data by perturbative QCD, cast into the DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) parton evolution equations [1] constitutes one of the major successes of QCD. At small enough Bjorken-x however, these equations are expected to break down. An alternative ansatz for the small x regime is the BFKL (Balitsky-Fadin-Kuraev-Lipatov) equation [2]. At lowest order the BFKL and DGLAP equations resum the leading logarithmic $(\alpha_s \ \ln 1/x)^n$ or $(\alpha_s \ \ln(Q^2 \ /Q_0^2))^n$ contributions respectively, with Q^2 being the virtuality of the exchanged photon. The leading log DGLAP ansatz corresponds to a strong ordering ($Q_0^2 \ll k_T{}_1^2 \ll ...k_T{}_i^2 \ll ...Q^2$) of the transverse momenta k_T (w.r.t. the proton beam) in the parton cascade (Fig. 1) while in the BFKL ansatz they rather follow a kind of random walk ($k_T{}_i^2 \approx k_T{}_{i+1}^2$) [3]. It is an open theoretical question to what extent BFKL type contributions play a rôle in the small x ($\approx 10^{-4}$) regime now accessible in deep inelastic scattering (DIS) at HERA. Measurements on the hadronic final state emerging from the

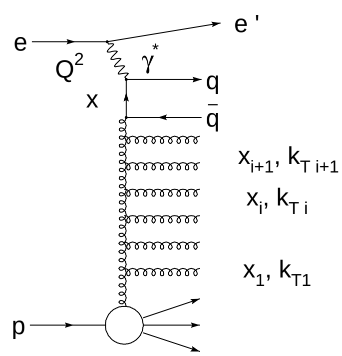

Figure 1: Parton evolution in the ladder approximation. The longitudinal fractional momenta x_i and transverse momenta k_{Ti} of subsequently emitted partons are indicated.

cascade could be sensitive to the new type of evolution. For example, without the restriction of strong k_T ordering, more transverse energy E_T is expected from BFKL than from DGLAP parton radiation in a region between the current region and the proton remnant [5]. Though the HERA E_T flow data [4] can be interpreted consistently with the BFKL mechanism, it was not possible to disentangle the perturbative parton radiation from non-perturbative hadronization effects [6, 7].

In this paper it will be demonstrated that single particle transverse momentum (p_T) spectra represent a more direct measure of the partonic activity than the E_T flow measurements. Observables are then constructed which allow to discriminate the k_T ordered from the unordered parton shower scenario.

Predictions for the cases of the ordered resp. unordered cascades are extracted from Monte Carlo models, which incorporate the QCD evolution in different approximations and utilize phenomenological models for the non-perturbative hadronization phase. The MEPS model (Matrix Element plus Parton Shower) [8], incorporates the QCD matrix elements up to first order, with additional soft emissions generated by adding leading log parton showers. In the colour dipole model (CDM) [9, 10] radiation stems from colour

dipoles formed by the colour charges. Both programs use the Lund string model [11] for hadronization. The Herwig model [12] is also based upon leading log parton showers, with additional matrix element corrections [13]. It uses a cluster fragmentation scheme [14]. The CDM description of gluon emission is similar to that of the BFKL evolution, because the gluons emitted by the dipoles do not obey strong k_T ordering [15]. In MEPS and Herwig the partons are strongly ordered in k_T , because they are based upon leading log DGLAP parton showers. The latest versions of the models (Lepto 6.4 for MEPS, Ariadne 4.08 for CDM and Herwig 5.8) are used with the parton density parametrization MRSH [16]. They provide a satisfactory overall description of current DIS final state data [17], in particular of the E_T flows [1].

2 The Method

In this section the sensitivity of single particle p_T spectra to the parton activity in the ladder is demonstrated. Generated events are selected from the kinematic plane of x and Q^2 according to the binning chosen by H1 [4]. Events from two bins, one at "low x " ($\langle x \rangle$=0.00037) and one at "high x " ($\langle x \rangle$=0.0023), with $\langle Q^2 \rangle \approx 14$ GeV^2 approximately constant, are compared. In Fig. 2 a the E_T flow in the hadronic centre of mass system CMS is shown [2] as a function of pseudorapidity η ($\eta = -\ln\tan\theta/2$, where the angle θ is measured w.r.t the virtual photon direction) for events with small x . As expected, the partons produced from unordered emission (CDM) give more E_T in the central η region $\eta \approx 0$ than the ones emitted from the ordered cascade (MEPS, Herwig). However, the observable particles emerging after hadronization give rise to very similar E_T flows, unresolvable with current data [4, 17]. While hadronization adds relatively little E_T to the partonic E_T for CDM, most of the E_T is generated by hadronization in the cases of MEPS and Herwig. To answer the question whether the E_T observed in the data is generated predominantly by parton radiation or by hadronization, inclusive p_T spectra are considered. Hadronization should produce typical spectra which are limited in p_T , while parton radiation should manifest itself in a hard tail of the p_T distribution. That tail is due to occasional hard parton radiation, from which hard particles can emerge. The production of such hard particles from hadronization would be suppressed.

To test this idea particles from a "central" η interval $0 < \eta < 2$ are examined. The lower limit is given by the approximate acceptance of the HERA detectors, and the upper limit restricts the interval to the region where the partonic differences in E_T are largest, excluding the "current" fragmentation region. Events are compared which have similar hadronic E_T in that interval ($E_T^{\rm had}$ between 1 and 2 GeV/unit rapidity), but different amounts of partonic E_T , $E_T^{\rm par}$. Events with $E_T^{\rm par} < 0.2$ GeV/unit rap. are called hadronization dominated, and events with $E_T^{\rm par} / E_T^{\rm had} > 0.5$ are called parton dominated. The correlation between $E_T^{\rm par}$ and $E_T^{\rm had}$ is shown in Fig. 2 b. For the CDM two classes of events can be identified. For one class $E_T^{\rm had}$ is well correlated with $E_T^{\rm par}$, for the other

[1] In MEPS the new concept of soft colour interactions [7] had to be introduced to reach the level of E_T seen in the data [4, 17]. Intriguingly, this mechanism also produces rapidity gap events [18] at a rate comparable to observation [7], roughly 10%. Rapidity gap events are also produced by the cluster fragmentation in Herwig. In this paper rapidity gap events are excluded.

[2] All distributions shown are normalized to the number of events N which enter the distribution.

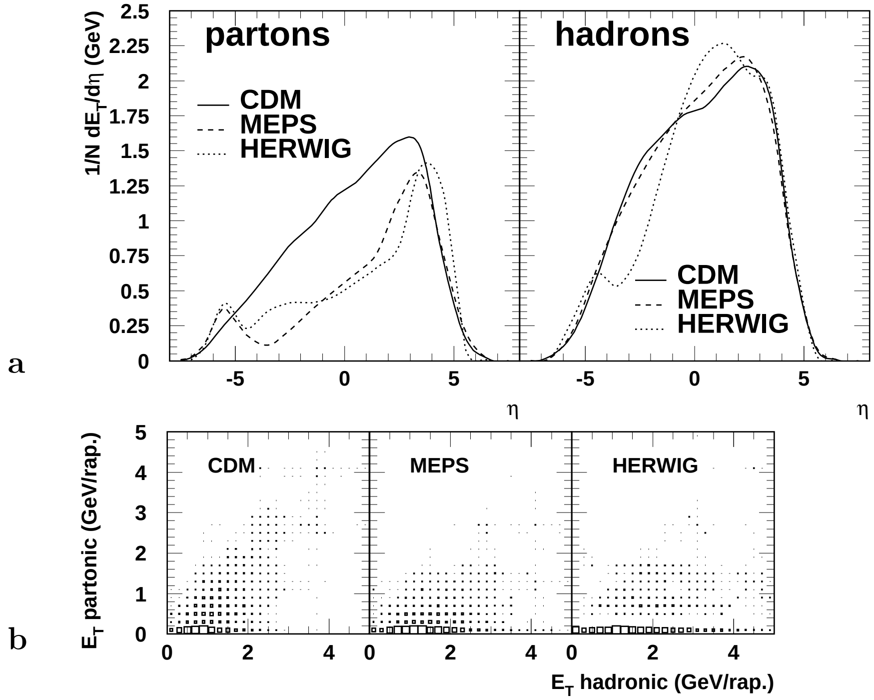

Figure 2: **a)** Transverse energy flows vs. pseudorapidity η generated by the models CDM, MEPS and Herwig for partons and for hadrons at "low x ". The proton direction is to the left. **b)** Correlation between partonic and hadronic E_T produced in the central pseudorapidity bin $0 < \eta < 2$ for CDM, MEPS and Herwig.

E_T^{par} is small, regardless of E_T^{had} . For the other models, most events fall into the latter class, while the correlation between E_T^{par} and E_T^{had} is much less pronounced for the rest of the events. The parton dominated events indeed exhibit a harder p_T spectrum than the hadronization dominated events (s. Fig. 3 a), regardless of the underlying parton dynamics or the applied hadronization model. Therefore p_T spectra provide a useful method to study the underlying parton dynamics in DIS.

3 Predictions

In this section observables are constructed that should allow to distinguish between the two scenarios of ordered resp. unordered parton evolution, or in general be sensitive to the parton radiation generated in the evolution. In this study the CDM is taken as a model to represent the unordered parton cascade, and the MEPS and Herwig models represent the ordered cascade. In Fig. 3 b the inclusive p_T spectra of charged particles from the "central" η bin are shown for large and for small x . At large x , all models predict similar p_T spectra. At small x however the tail of the distribution (p_T larger than $\simeq 1.5$ GeV) is harder for the unordered model (CDM) than for the others, as expected given the larger parton activity. Less visible due to the logarithmic scale is a difference in the average charged multiplicity in the central η region between the two scenarios of about 20%. In MEPS and Herwig more soft particles are produced in the hadronization

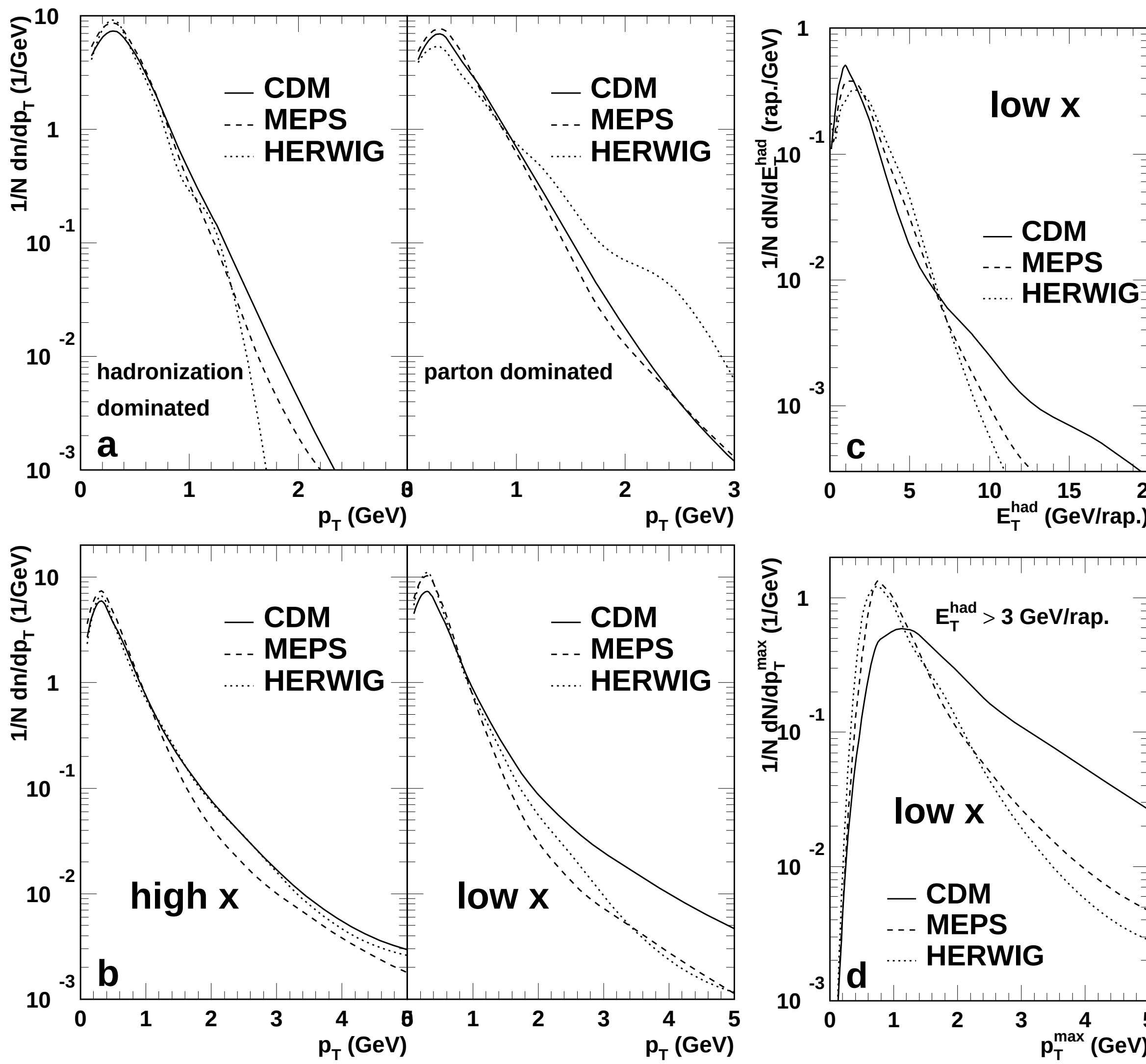

Figure 3: **a)** Transv. momentum (p_T) spectra of charged particles from the central pseudorapidity bin $0 < \eta < 2$ for events which are either hadronization dominated or parton dominated. **b)** Ch. particle p_T spectra from $0 < \eta < 2$ for events with "high x" and with "low x". **c)** Event distribution in the quantity $E_T^{\rm had}$, determined from $0 < \eta < 2$, at "low x". **d)** Distribution of the maximal transv. momentum $p_T^{\rm max}$ of ch. particles from $0 < \eta < 2$ for events with $E_T^{\rm had} > 3$ GeV /unit rap. at "low x".

phase to generate the E_T seen in the data.

One also notices from Fig. 3 b that from the unordered cascade a hardening of the spectrum is predicted towards small x, and a softening otherwise. This behaviour can be traced to the fact that while all models predict an increase of $E_T^{\rm had}$ towards small x, as observed in the data [4], only the CDM shows that increase also on the parton level (see Fig. 4). The other models predict a decreasing $E_T^{\rm par}$. This behaviour of the models is in accord with perturbative calculations of the central E_T as a function of x [5], based upon either the BFKL or DGLAP evolutions. As a consequence, the relative amount of hadronization to $E_T^{\rm had}$ decreases for CDM, but increases for MEPS and Herwig towards small x. The signal can be enhanced by selecting events in which large $E_T^{\rm had}$ (s. Fig. 3 c)

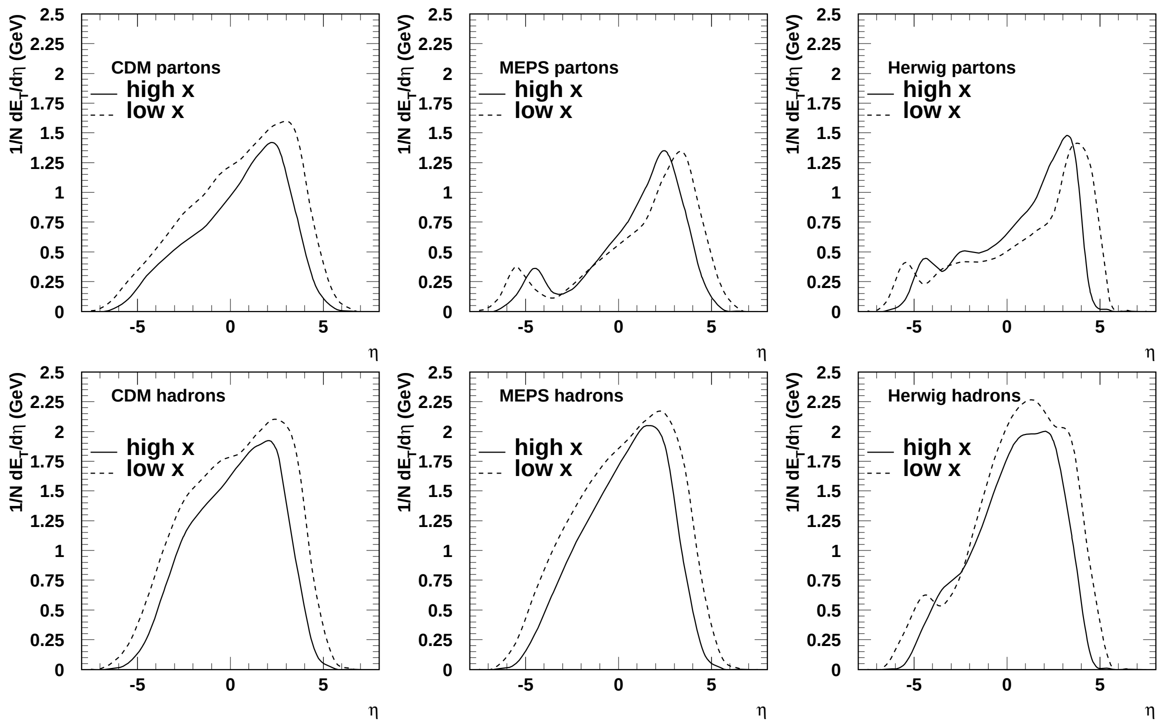

Figure 4: E_T flows vs. pseudorapidity for CDM, MEPS and Herwig on the parton and on the hadron level. Compared are the E_T flows for "high" and "low" x .

is observed (e.g. calorimetrically), because in CDM that is correlated with large $E_T^{\rm par}$, as opposed to the other models. For such events a dramatic signal can be obtained by measuring the maximal p_T observed in the central η region, s. Fig. 3 d. Enhanced parton radiation would also be signaled in the tail of the $E_T^{\rm had}$ distribution, s. Fig 3 c.

4 Conclusions

In order to investigate the dynamical features of parton evolution in the proton at small x , observables based on single particle p_T spectra have been constructed. It has been demonstrated for all models investigated that the hardness of such spectra is sensitive to parton radiation from the cascade. Since for small enough x it is expected that the DGLAP equations with strong k_T ordering for parton radiation cease to be valid, and may possibly be substituted by the BFKL ansatz, predictions are obtained for the two scenarios of ordered resp. unordered cascades. They have been derived from different Monte Carlo models which either obey k_T ordering or do not underlie such a restriction. The unordered scenario gives rise to a harder p_T spectrum in the central rapidity region of the hadronic CMS than the ordered one. It is further predicted that the p_T spectrum becomes harder resp. softer with decreasing x for the unordered resp. ordered scenario. The application of the presented method at HERA would not only allow to discriminate between the different QCD models, it would also offer the possibility to resolve the question of k_T ordered vs. unordered cascade, or DGLAP- vs. BFKL- like evolution at small x .

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